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Charged current interactions in $e^{\pm}p$ scattering at H1 with longitudinally polarized lepton beams

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The measurement of the cross section for charged current deep inelastic scattering in the $e^{\pm}p$ collisions with longitudinally polarized lepton beams in the H1 experiment at HERA-II is presented. Double and single differential cross sections are measured for the region of negative four momentum transferred squared $Q^2 \geq 300$ GeV^2. The measured cross sections are in a good agreement with the predictions of the Standard Model. The polarized total CC cross sections demonstrate expected linear dependence on the polarization. The cross sections from HERA-II are combined with the previous measurements from HERA-I to improve the statistical uncertainty of the unpolarized cross sections measurements.

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1. Introduction

At HERA 27.6 GeV leptons (electrons and positrons) were collided with the 920 GeV protons, leading to an *ep* center-of-mass energy of 320 GeV. During the second phase of HERA program (HERA-II, 2003-2007), the machine provided the longitudinal polarization of the lepton beam.

Transverse polarization of the lepton beam arises through synchrotron radiation via the Sokolov-Ternov effect[1]. As a part of the HERA upgrade in the year 2000 spin rotators that rotate the polarization into the longitudinal direction and back were installed in the lepton beamline around the collision regions of H1 and ZEUS experiments. The polarization is continuously measured using two independent polarimeters. The corresponding luminocity and longitudinal lepton beam polarisation for the left-handed (L) and right-handed (R) electron and positron data samples are given in Tab. 1.

In this contribution measurements of the charged current (CC) cross sections, $\sigma_{\rm CC}^{\rm tot}$, $d\sigma/dQ^2$ and the reduced double differential cross section $\tilde{\sigma}(x,Q^2)_{\rm CC}$ are reported for two values of longitudinal polarization, $P_e = (N_R - N_L)/(N_R + N_L)$, with N_R (N_L) being the number of the right (left) handed leptons in the beam.

The cross sections from HERA-II are combined with the previous measurements from HERA-I to improve the statistical uncertainty of the unpolarized cross sections measurements.

2. Charged Current Cross Section

The measured double differential CC cross section for collisions of polarized leptons with unpolarized protons may be expressed as

$$\frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = (1-P_e)\frac{G_F^2}{2\pi x}\left[\frac{M_W^2}{M_W^2+Q^2}\right]^2 (Y_+W_2^{\pm} - Y_{\pm}xW_3^{\pm} - y^2W_L^{\pm}), \tag{2.1}$$

where x is the Bjorken x variable and y is the inelasticity of the interaction, G_F is Fermi constant, M_W is mass of the W boson. The $e^{\pm}p$ cross section depends on the CC structure functions $W_2^{\pm}$, $xW_3^{\pm}$ and $W_L^{\pm}$. The helicity dependence of the weak interaction are contained in $Y_{\pm} = 1 \pm (1-y)^2$.

It is convenient to derive the CC reduced cross section $\tilde{\sigma}_{\rm CC}$ in which the dominant part of the Q^2 dependence of the cross section (2.1) due to W-propagator is removed

$$\tilde{\sigma}_{\rm CC}(e^{\pm}p) = \frac{2\pi x}{G_F^2}\left[\frac{M_W^2+Q^2}{M_W^2}\right]^2 \frac{d^2\sigma(e^{\pm}p)}{dxdQ^2} = (1-P_e)[Y_+W_2^{\pm} - Y_{\pm}xW_3^{\pm} - y^2W_L^{\pm}]. \tag{2.2}$$

In the quark parton model (QPM), where $W_L^{\pm} = 0$, the structure functions $W_2^{\pm}$ and $xW_3^{\pm}$ may be expressed as the sum and difference of the quark and anti-quark momentum distributions, $xq(x,Q^2)$ and $x\overline{q}(x,Q^2)$:

$$W_2^{-} = x(u+c+\overline{d}+\overline{s}), \qquad W_2^{+} = x(\overline{u}+\overline{c}+d+s), \tag{2.3}$$

$$xW_3^{-} = x(u+c-\overline{d}-\overline{s}), \qquad xW_3^{+} = x(d+x-\overline{u}-\overline{c}). \tag{2.4}$$

The cross section has a linear dependence on the polarization of the electron beam P_e. For a fully right handed electron beam, $P_e = 1$, or a fully left handed positron beam, $P_e = -1$, the cross section is expected to be identically zero in the Standard Model.

	R	L
$e^- p$	$\mathscr{L} = 45.9\ \mathrm{pb}^{-1}$	$\mathscr{L} = 103.2\ \mathrm{pb}^{-1}$
	$P_e = (+36.9 \pm 2.3)\%$	$P_e = (-26.1 \pm 1.0)\%$
$e^+ p$	$\mathscr{L} = 98.1\ \mathrm{pb}^{-1}$	$\mathscr{L} = 81.9\ \mathrm{pb}^{-1}$
	$P_e = (+32.5 \pm 1.2)\%$	$P_e = (-37.6 \pm 1.4)\%$

Table 1: Table of integrated luminosities, $\mathscr{L}$, and luminosity weighted longitudinal polarization, P_e for the data sets presented.

3. Experimental Technique and Measurement Procedure

The H1 detector components most relevant to this analysis are the liquid argon calorimeter (LAr), which measures the positions and energies of charged and neutral particles over the polar[1] angular range $4^\circ < \Theta < 154^\circ$, and the inner tracking detectors, which measure the angles and momenta of charged particles over the range $7^\circ < \Theta < 165^\circ$. A full description of the detector can be found in [2].

The CC events are characterised by large unbalanced transverse momentum, $P_{t,h}$, attributed to the undetected neutrino. The quantity $P_{t,h}$ is determined as $P_{t,h} = \sqrt{(\sum_i p_{x,i})^2 + (\sum_i p_{y,i})^2}$, where the summation is performed over all particles of the hadronic final state.

The CC kinematic quantities are determined from the hadronic final state using the method introduced by Jacquet and Blondel[4]

$$y_h = \frac{E_h - p_{z,h}}{2E_e}, \qquad Q_h^2 = \frac{(P_{t,h})^2}{1 - y_h}, \qquad x_h = \frac{Q_h^2}{s y_h}, \tag{3.1}$$

where $E_h - p_{z,h} = \sum_i (E_i - p_{z,i})$ and E_e is the incident electron beam energy.

The CC candidates are selected by requiring $P_{t,h} > 12\ \mathrm{GeV}^2$ and reconstructed vertex to be within 35 cm in z around the nominal interaction position. In order to ensure high trigger efficiency and good kinematic resolution the analysis is restricted to the domain $0.03 < y_h < 0.85$. Non-ep background is rejected by searching for typical beam-induced and cosmic muon background event topologies[5]. The suppression cuts are different for R and L data sets as the relative photoproduction contributions differ in the two samples. The residual ep background is negligible for most of the measured kinematic domain. The simulation is used to estimate this contribution, which is subtracted statistically from the CC data sample.

4. Results

The measured total CC cross sections are quoted in the range $Q^2 > 400\ \mathrm{GeV}^2$ and $y < 0.9$ are shown in Fig. 1a. The measurement of the unpolarized total cross section in the same phase space using HERA-I data is also given. The measurements are compared to expectations of the Standard Model using the H1 PDF 2009[3] parametrisation. The data exhibit a clear linear polarization dependence of the cross section which is maximal for purely left handed $e^- p$ scattering and

[1]The polar angle Θ is defined with respect to the positive z axis, the direction of the incident proton beam.

purely right handed e^+p scattering in accordance with the parity violation in weak charged current interactions in the Standard Model.

Measurements of the single differential cross section $d\sigma/dQ^2$ have been made for the L and R samples and found to be in a good agreement with the theoretical predictions over four orders of magnitude of the measured cross section. The e^-p R sample is shown in Fig. 1b with the theoretical expectation based on the PDFs from the H1 PDF 2009 fit.

The double differential cross sections $d^2\sigma/dxdQ^2$ were measured for four data sets: R and L, e^+p and e^-p. The reduced cross sections for electrons are shown in Fig. 2a. The L and R samples are averaged into an effective unpolarized data sets (correcting for the small residual polarization). The resulting cross sections are then averaged with previously published H1 measurements of the unpolarized cross sections[6] from HERA-I using the method described in [7]. The final combined cross sections make use of the complete HERA data set collected by H1 and amounts to a total luminosity of 165.5 pb^{-1} of e^-p and 280.8 pb^{-1} for e^+p scattering. The combined reduced cross section for electrons for the full HERA is shown in Fig. 2b.

These measurements of the double differential $e^{\pm}p$ CC cross sections are for essential in the flavour separation in the QCD PDF fit.

5. Summary

Measurements of polarized $e^{\pm}p$ charged current cross section σ_{CC}^{tot}, $d\sigma/dQ^2$ and $\tilde{\sigma}_{CC}(x,Q^2)$ using the HERA-II data set have been done. The results are based on data collected from collisions of unpolarized protons with longitudinally polarized leptons. The polarization dependence of the charged current cross section had been measured at HERA, extending tests of the chiral structure of the charged current interations into the region of large, space-like Q^2. The data are found to be consistent with the Standard Model predictions.

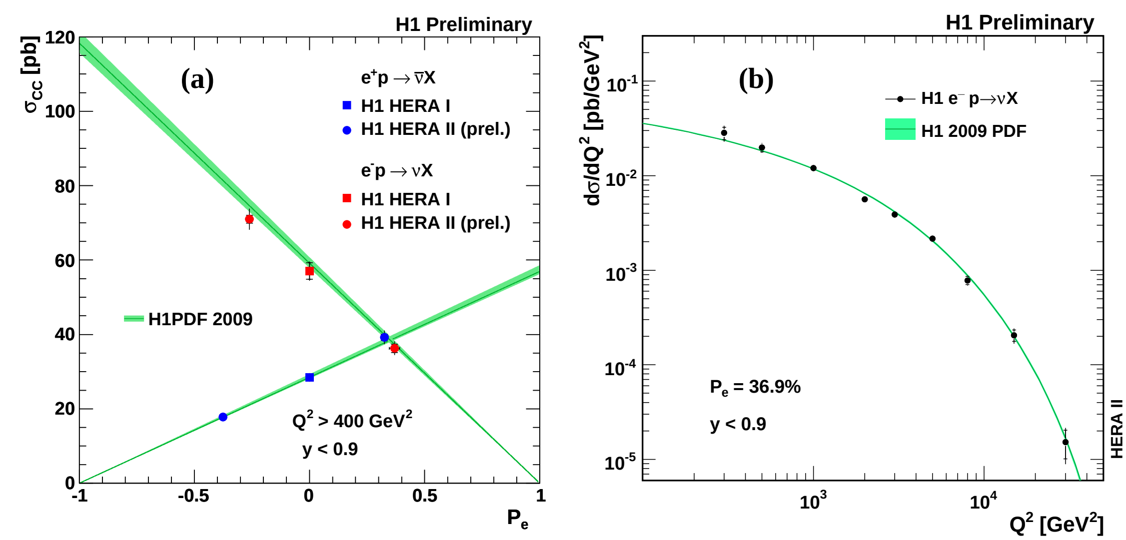

Figure 1: **(a)** The dependence of the $e^{\pm}p$ CC cross section on the lepton beam polarization P_e. **(b)** The Q^2 dependence of the $d\sigma/dQ^2$, shown for the e^-p R data sample. Both measurements are compared to the Standard Model prediction based on the H1 PDF 2009 parametrisation.

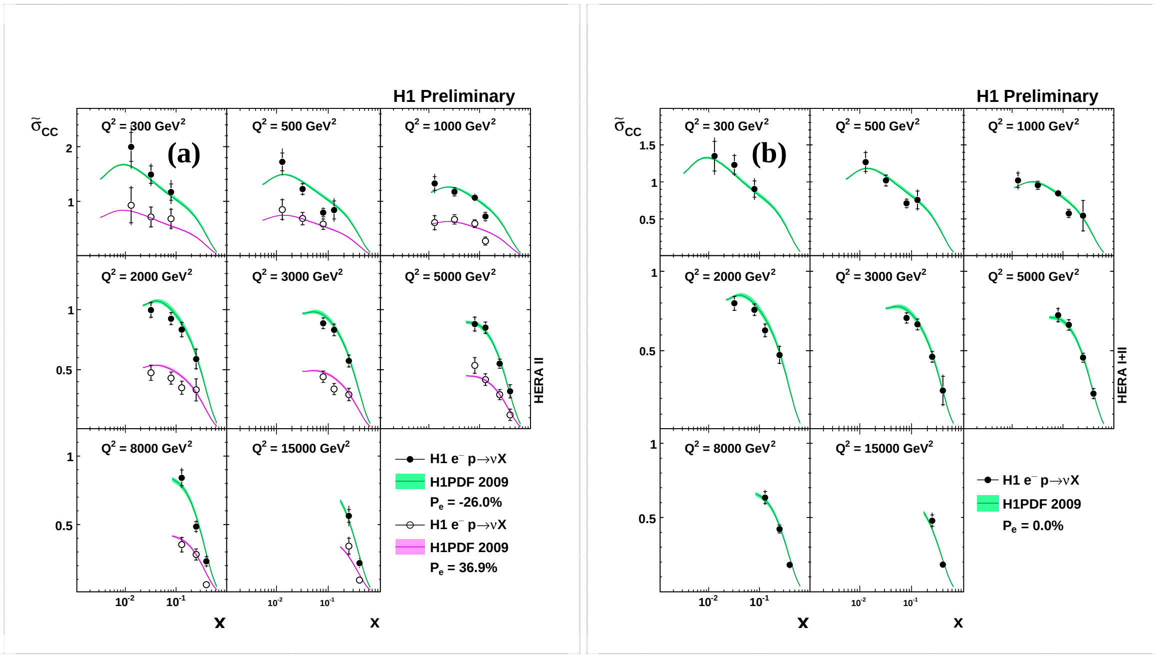

Figure 2: **(a)** The reduced cross section $\tilde{\sigma}_{CC}$ in polarized L and R $e^- p$ scattering with HERA-II data. **(b)** The reduced cross section $\tilde{\sigma}_{CC}$ in unpolarized $e^- p$ scattering using complete H1 data set. Both measurements are compared to the Standard Model prediction based on the H1 PDF 2009 parametrisation.

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